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(54) Method and apparatus for direct deposition of ceramic coatings.

(57) A method and apparatus for coating high temperature resistant, electrically-conductive, ceramic compounds, such as titanium carbides and diborides, onto an organic substrate, which may be an organic resin matrix composite. The apparatus basically comprises a vacuum arc plasma generator, a high-voltage insulated target holding table and a plasma channel. The plasma generator includes a vacuum chamber having a cylindrical cathode of the material to be deposited, surrounded by a ceramic insulator which is in turn surrounded by a metal trigger ring in contact with a trigger electrode. When a vacuum arc discharge is initiated, a plasma flows outwardly from the cathode through a hole in an adjacent anode and into a drift tube. The drift tube has a plurality of magnets around the tube exterior to push the plasma away from the tube, maintain a uniform plasma density and guide the plasma towards a target on a movable high voltage insulated target support. The cathode material is nearly 100% ionized, giving the ions impinging on the organic target sufficient kinetic energy to react with and adhere tightly to the target substrate without additional heating. The amount of kinetic energy is controllable to provide the selected degree of target surface ion mixing with the coating elements.

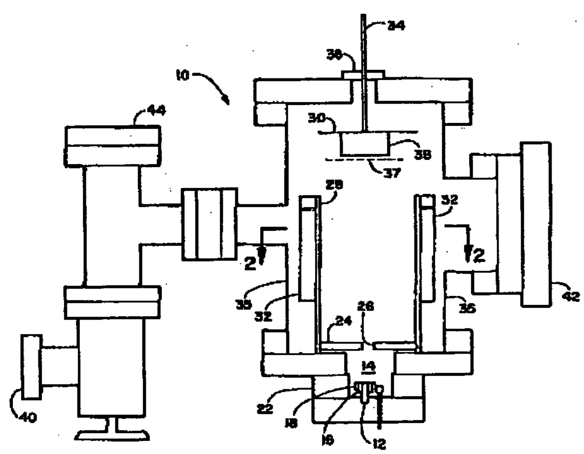

FIGURE 1

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BACKGROUND OF THE INVENTION

This invention relates in general to the formation of electrically-conductive ceramic compound coatings on substrates and, more particularly, to the direct ion mixed plasma deposition of such compounds onto organic substrates such as organic matrix composites.

A number of different methods have been developed for depositing materials, generally metals, in the form of particles or ions onto a target surface to form an adherent, uniform coating. Among these are thermal deposition, cathode sputtering, chemical vapor deposition. While useful in particular applications, these methods suffer from several problems, including a tendency to coat other system surfaces than the target with the material being deposited, requiring frequent cleaning, contamination problems when the coating material is changed and a waste of often expensive coating material. Generally, these processes require that the target surface be heated to a very high temperature which often damages the target material, especially when the target is an organic material or an organic matrix composite material. The high deposition temperatures also lead to thermal stresses that may cause coating delamination.

Vacuum arc deposition has a number of advantages for coating difficult materials, such as refractory metals, onto targets. Vacuum arc deposition involves establishing of an arc, in a vacuum, between a cathode formed from the coating material and an anode, which results in the production of a plasma of the cathode material suitable for coating. The process does not involve gases, making control of deposition rate easier and simplifies changing coating materials. Typical vacuum arc deposition systems are described in U.S. Patents Nos. 3,566,185, 3,836,451 and 4,714,860. Vacuum arc deposition, sometimes referred to as cathodic arc deposition, is used commercially, typically to produce titanium nitride coatings on tooling.

A number of problems remain, however, which limit the use of vacuum arc deposition. Coatings often suffer from adherence and low density problems, particularly when an organic matrix composite material is used as the target. Difficulties are often encountered in obtaining a desired coating composition where ceramic materials, such as electrically-conductive ceramic compounds (e.g., borides, nitrides or carbides) are being applied.

Thus, there is a continuing need for improved methods and apparatus for forming uniform, adherent coatings from metal compounds, in particular on organic matrix composite target substrates.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide an improved method and apparatus capable of forming adherent coatings of high temperature resistant, electrically-conductive, ceramic compounds on organic substrates. Another object is to provide a method and apparatus capable of producing smooth, hard, electrically-conductive ceramic coatings having uniform high density on organic substrates. A further object is to form, by ion mixed plasma techniques, coatings of electrically-conductive ceramic compounds having precise stoichiometry. Yet another object is to form coatings of electrically-conductive ceramic compounds on organic substrates having a diffuse interface between coating and substrate.

The above-noted objects, and others, are accomplished in accordance with this invention by a method and apparatus using a direct ion mixed plasma deposition system. The apparatus basically comprises a vacuum chamber enclosing vacuum arc plasma generator, an anode, and a high voltage insulated table for holding a target to be coated.

The plasma generator includes a cylindrical cathode formed from the compound to be deposited, surrounded by a ceramic electrical insulator which is in turn surrounded by a metal trigger ring in contact with a trigger electrode. The anode is typically a copper plate having a central hole for passage of the plasma.

A plasma channel or drift tube may be included to surround the plasma between anode and target. This channel, if used, typically is a tube of copper or other non-magnetic material with the opening extending from the anode hole to a location adjacent to the target table. The channel serves to guide the plasma to the target and to increase plasma uniformity. A plurality of magnets, preferably samarium-cobalt magnets, are located in a circle around the volume between anode and target. If a plasma channel is used, the magnets are attached to the outside of the tube in a manner such as to form a ring of magnetic cusps around the interior of the plasma channel. These cusps push plasma away from the tube interior wall, guide the plasma to the target and keep the plasma density uniform.

The basic process of this invention includes evacuating the chamber, initiating ionization at the cathode to form a plasma between the anode and cathode, directing the plasma through the hole in the anode and along the drift tube or channel and coating the ions from the plasma onto the organic target material. Preferred steps, materials and conditions are discussed in detail below.

BRIEF DESCRIPTION OF THE DRAWING

Details of the invention, and of certain preferred embodiments thereof, will be further understood upon reference to the drawing, wherein:

Figure 1 is a schematic diagram of the plasma deposition apparatus of this invention; and

Figure 2 is a transverse section view through the plasma drift tube or channel, taken on line 2--2 in Figure 1.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to Figure 1 there is seen a schematic representation of a vacuum chamber 10 containing the apparatus for direct ion mixed plasma deposition. A cathode 12 is positioned in a chamber 14. Any suitable metal compound may be used to form cathode 12. Typical such compounds include those selected from the group consisting of borides, carbides, silicides and nitrides of titanium, tungsten, aluminum, molybdenum, niobium and tantalum and mixtures thereof. Best results are obtained with titanium diboride, titanium carbide, titanium nitride, tungsten carbide and mixtures thereof. In many cases high temperature resistant, electrically-conductive ceramics are preferred for maximum hardness and abrasion resistance. Optimum results are obtained with titanium diboride for high temperature applications due to its hardness, stability and resistance to oxidation up to about 1200°F. Cathode 12 may have any suitable diameter, typically from about 3 to 10 mm.

Cathode 12 is surrounded by an insulating ring 16, formed from any conventional suitable material. A trigger ring 18, typically steel, is formed around insulating ring 16. A conventional trigger 20 is placed in contact with trigger ring 18. The walls 22 of chamber 14 are formed from any conventional electrically insulating material. If desired, the multiple cathode assembly as shown in U.S. Patent No. 5,089,707 can be used in place of the cathode assembly shown. This would permit the rapid and convenient application of plural layers of different materials.

An anode 24 is positioned on the opposite side of chamber 14 from cathode 12. Anode has at least one perforation 26 generally aligned with cathode 12. Anode 26 is formed from any suitable conductor, such as copper.

A channel or drift tube 28, typically having a diameter of from about 100 to 200 mm, may extend from anode 26 toward an insulated target support structure 30. Channel 28 may be omitted if desired. Tube 28 is formed from a non-magnetic metal, such as copper. A plurality of permanent magnets are arranged around the exterior of tube 28 in a pattern as shown in Figure 2. Other support means will be provided for magnets 32, such as conventional brackets on the interior of vacuum chamber walls, if drift tube or channel 28 is eliminated. While any suitable magnets may be used, cobalt-samarium magnets are preferred for optimum performance. While any suitable even number of magnets may be used, an even number from about 4 to 12 is preferred. The larger the diameter of tube the greater the number of magnets that will be optimum. Preferably , the magnets are spaced from about 10 to 20 mm apart, edge-to-edge. Magnets 32 are arranged with like poles of adjacent magnets facing each other.

Support table 30 is formed from a high voltage insulating material and is mounted on a mechanism 36 extending through a high-voltage feed-through 34 in the wall of vacuum chamber 10 to permit the distance from the table to drift tube 28 to be varied.

The organic target substrate 38 to be coated is secured to support 30 in a conventional manner. Any suitable organic material can be coated in this apparatus, including relatively low melting temperature materials. Typical materials include composites of fibers in an resin matrix, such as graphite fibers in an epoxy resin matrix, carbon-carbon materials, etc.

If target 38 is insulating, in order to apply a negative bias to the target, a conductive screen 37 or the like is placed over the target surface and the desired bias is applied to the screen.

Vacuum chamber 10 includes the usual operational components, such as a connection 40 to a roughing vacuum pump, a connection 42 to a high vacuum pump and an ion gauge 44 to measure the degree of vacuum achieved.

In the operation of this apparatus, a suitable organic material target 38 is placed on the target support table 30 and a cathode 12 of a selected metal compound is installed. The chamber 10 is pumped down to a suitable vacuum through connections 40 and 42. When a high voltage is applied between trigger ring 18 and cathode 12, a vacuum arc discharge is initiated from a tiny spot (typically less than one micrometer in diameter) on the cathode surface. The current density in this spot is enormous, well over one million amperes per square inch. So large is the current density that material from the cathode is pulled from the surface and ionized. Ionization is almost total, to the extent that most of the ions are multiply charged. The trigger pulse typically lasts only about a tenth of a millisecond, just long enough to initiate the vacuum arc breakdown.

The plasma from this arc fills the cavity 14 between cathode 12 and anode 24 so that a relatively low (typically about 20 volts) voltage between the cathode and anode is sufficient to sustain the

arc. For a typical titanium diboride cathode, the plasma will consist of a combination of titanium ions and boron ions, with twice the number of boon ions as titanium ions. The ionization is nearly 100%. It is so extensive that most of the titanium ions will be doubly charged.

The plasma produced by the arc flows outward from cathode 12 through the hole 26 in anode 24 and into plasma drift tube or channel 28. The channel guides the plasma towards target 38.

The coating is applied by exposing the target surface to the plasma while typically maintaining the target surface at a bias of from about 50 to 200 volts negative. In this way, the plasma ions are drawn to the surface with enough energy to form the appropriate bonds but with little sputtering of the surface or surface penetration. The coating is thus plasma deposited without ion mixing.

In a second embodiment of the coating step, the target bias is alternately varied from about 50 to 200 volts negative to about 10 to 30 kilovolts negative. Preferably, the bias is varied at a frequency of from about 10 to 30 cycles per second. This causes the coating to be sequentially applied and ion mixed by itself. The ion mixing sequence helps densify the coating, further improves adhesion and applies additional compressive stress to the coating. This compressive stress helps keep the coating from cracking, particularly where differences in the coefficient of thermal expansion produces stresses.

The deposition is continued for the time necessary to produce a coating of the desired thickness, typically from about 3 to 10 micrometers. If desired, multiple layers of different compounds can be produced by changing the composition of cathode 12. This is particularly convenient with this method and apparatus, since little, if any, of the material is deposited on the chamber walls, etc. from which it could be released to contaminate later layers of different composition.

To maximize the adherence of the coating to the target surface, that surface should be clean of any impurities. Conventional cleaning techniques often do not remove all of the material from the target surface that can interfere with coating adherence. Thus, it may be preferable to sputter away a small amount of the surface to improve cleaning.

In accordance with the method of this invention, the target surface is partially ion implanted prior to applying the coating. Ion implantation strengthens the surface and provides the desirable sputter cleaning. Preferably, the materials used to implant the surface are the ones to be used to form the coating. In this manner, no impurities can be introduced into the system. In addition, adhesion is aided by eliminating any sharp interface between the coating and the treated surface. This implantation is preferably performed using the apparatus described above and the cathode that is to be used to form the coating. The plasma is formed as described above and the target structure is biased to a high negative voltage, preferably from about 10 to 30 kilovolts negative. The ions are drawn from the plasma to the target, impinging with sufficient energy to penetrate the surface deeply and produce an ion implanted layer. Typically, with a titanium diboride cathode, the surface is implanted with titanium and boron. The titanium ions penetrate into the surface approximately half the distance the boron ions penetrate. In order to prevent excessive heating of the target, ion implantation is conducted at a very low dose rate. Total ion implantation dose is preferably from about 3×10^{15} to 2×10^{17} atoms/cm^2, with optimum results at about 10^{17} atoms/cm^2. Without removing the target from the chamber, conditions are changed to the coating conditions described above and coating proceeds.

Other applications, variations and ramifications of this invention will occur to those skilled in the art upon reading this disclosure. Those are intended to be included within the scope of this invention, as defined in the appended claims.

Claims

1. Apparatus for forming a high temperature resistant, electrically-conductive, ceramic compound coating on an organic substrate by direct ion mixed plasma deposition which comprises:

   a vacuum chamber;

   a cathode assembly within said chamber, said cathode assembly comprising:

   a cathode comprising at least one high temperature resistant, electrically-conductive, ceramic compound;

   an electrically insulating ceramic ring around said cathode;

   a trigger ring around said insulating ring; and a trigger electrode in contact with said trigger ring;

   an anode spaced from said cathode, said anode having at least one perforation, said anode adapted to receive and pass ions from said cathode through said perforation; and

   a target support means spaced from said anode adapted to support a target to be coated with said target positioned to receive ions exiting said anode;

   a plurality of permanent magnets arranged around the volume between said anode and said target, said magnets arranged with like poles on adjacent magnets in a face-to-face pattern;

   whereby a uniform, adherent, substantially

stoichiometric, coating of said refractory compound is formed on said target.

2. The apparatus according to claim 1 further including a drift tube positioned to receive and guide ions exiting said anode, said guide tube comprising a tube of non-magnetic material.

3. The apparatus according to claim 1 wherein said target is formed from an electrically insulating material and further including an electrically conductive screen on the surface of said target toward said anode.

4. The apparatus according to claim 1 where said ceramic compound is selected from the group consisting of borides, carbides, silicides and nitrides of titanium, tungsten, aluminum, molybdenum, niobium and tantalum and mixtures thereof.

5. The apparatus according to claim 4 wherein said ceramic compound is selected from the group consisting of titanium diboride, titanium carbide, titanium nitride, tungsten carbide, and mixtures thereof.

6. The apparatus according to claim 1 wherein said drift tube is formed from copper.

7. The apparatus according to claim 1 wherein said magnets are samarium-cobalt magnets.

8. The apparatus according to claim 1 wherein said target is an organic resin matrix composite material.

9. The apparatus according to claim 1 additionally comprising a plurality of permanent magnets arranged around the volume between said anode and said target, said magnets arranged with like poles on adjacent magnets in a face-to-face pattern.

10. The method of forming a high temperature resistant, electrically-conductive, ceramic compound coating on a substrate by direct ion mixed plasma deposition which comprises the steps of:

providing a vacuum chamber containing, in seriatim, a cathode, a perforated anode, and a target comprising material on a target support;

said cathode comprising a high temperature resistant, electrically-conductive, ceramic compound;

initiating an arc at said cathode to form a mixed plasma moving toward and through said anode;

guiding said plasma toward said target while maintaining a substantially uniform ion mixture and plasma density;

impinging said plasma onto said target whereby a substantially stoichiometric adherent coating of said ceramic compound is formed on said target.

11. The method according to claim 10 including maintaining said target at a bias of from about 50 to 200 volts negative during deposition.

12. The method according to claim 10, including varying the bias on said target from about 50 to 200 volts negative to about 10 to 30 kilovolts.

13. The method according to claim 12 wherein said bias is varied at a frequency of from about 10 to 30 cycles per second.

14. The method according to claim 10 further including the step of cleaning the target surface by sputtering away a small amount of the target surface before applying the coating.

15. The method according to claim 14 wherein said cleaning is accomplished and ions are implanted in the target surface by initiating cathode ionization with the target at a bias of from about 10 to 30 kilovolt for a period sufficient to apply from about 3×10^{16} to 2×10^{17} atoms/cm^2.

16. The method according to claim 10 wherein said ceramic compound is selected from the group consisting of borides, carbides, silicides and nitrides of titanium tungsten, aluminum, molybdenum, tantalum, niobium and mixtures thereof.

17. The method according to claim 10 wherein said target comprises an organic resin matrix composite material.

18. The method according to claim 10 wherein said plasma is guided through said drift tube by imposing magnetic fields along the tube walls by securing a plurality of permanent magnets along the exterior of a non-magnetic tube with the like poles of adjacent magnets in a face-to-face arrangement to form magnetic cusps between adjacent magnets.

19. The method according to claim 10 wherein said substrate and said target material are organic.

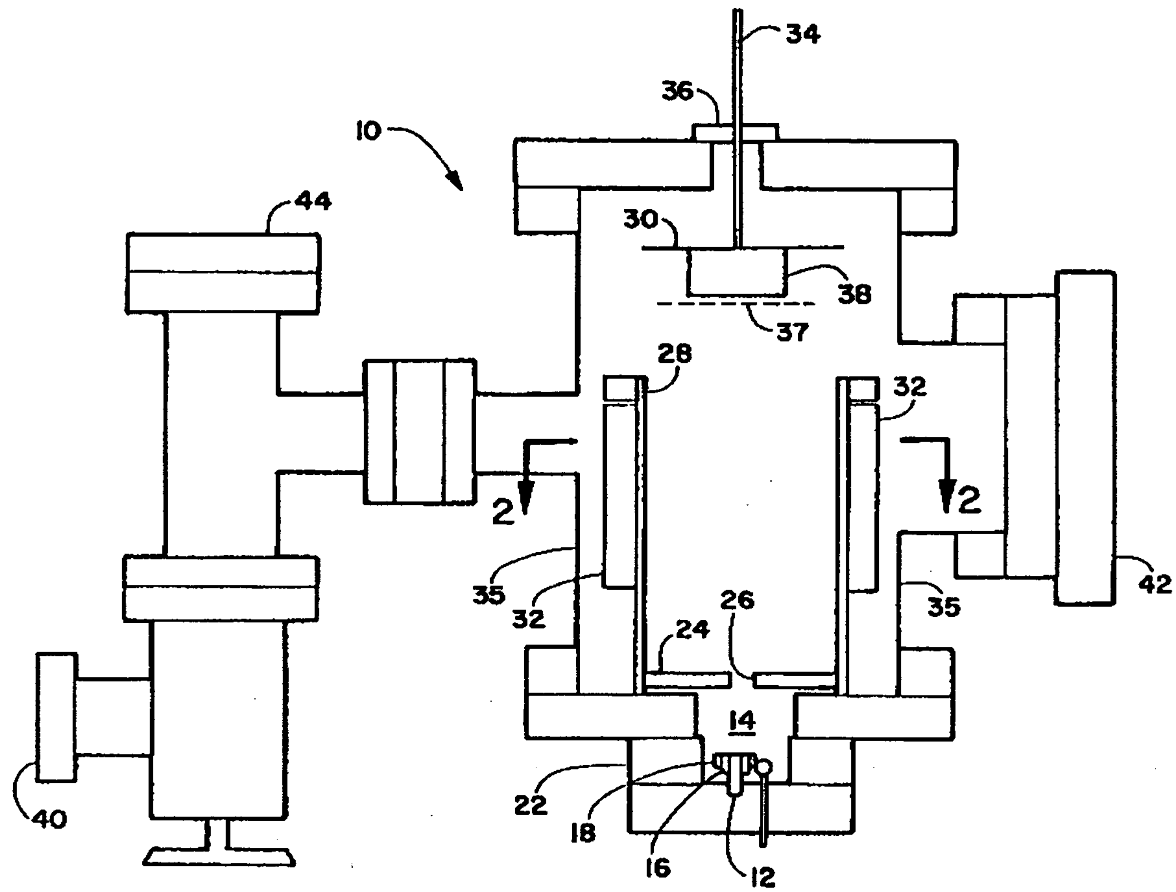

FIGURE 1

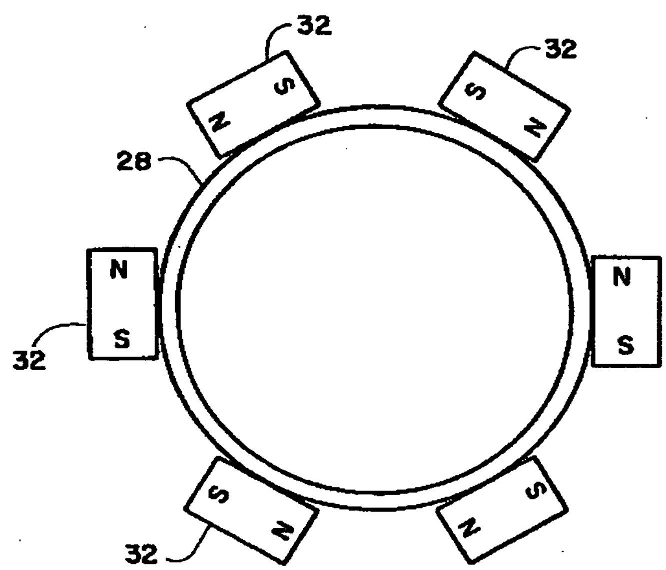

FIGURE 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93 30 3074

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	US-A-4 952 843 (BROWN ET AL.)	1,4,5,7,10,16	C23C14/32 H01J37/32 H01J27/08
A	* column 3, line 29 - column 4, line 34; figures 4,5 *	18	
Y	PATENT ABSTRACTS OF JAPAN vol. 13, no. 233 (C-601)29 May 1989 & JP-A-01 042 575 (KOBE STEEL) 14 February 1989 * abstract *	1,4,5,7,10,16	
A	GB-A-2 202 237 (VAC-TEC SYSTEMS) *page 5, lines 18-21; page 12, lines 1-20; Table I; claims 1, 8-10*	11-14,19	
A	EP-A-0 172 675 (APPLIED MATERIALS) * page 6, line 8 - line 16; figures 7,8 *	2	
A	FR-A-2 332 338 (BATELLE MEMORIAL INSTITUTE) * claims 1,15 *	3	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A,D	US-A-5 089 707 (MAGNUSON ET AL.)		C23C H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	13 OCTOBER 1993	PATTERSON A.M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

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